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FAILURE DETECTION AND IDENTIFICATION FOR A RECONFIGURABLE FLIGHT CONTROL SYSTEM

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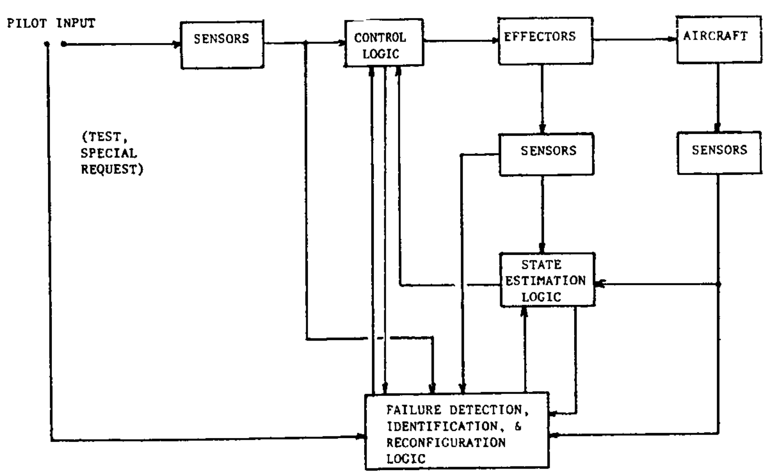
OVERVIEW OF THE BASELINE CONFIGURATION

Failure detection and identification logic for a fault-tolerant longitudinal control system were investigated. Aircraft dynamics were based upon the cruise condition for a hypothetical transonic business jet transport configuration. The fault-tolerant control system consists of conventional control and estimation plus a new "outer loop" containing failure detection, identification, and reconfiguration (FDIR) logic. It is assumed that the additional logic has access to all measurements, as well as to the outputs of the control and estimation logic. The pilot also may command the FDIR logic to perform special tests.

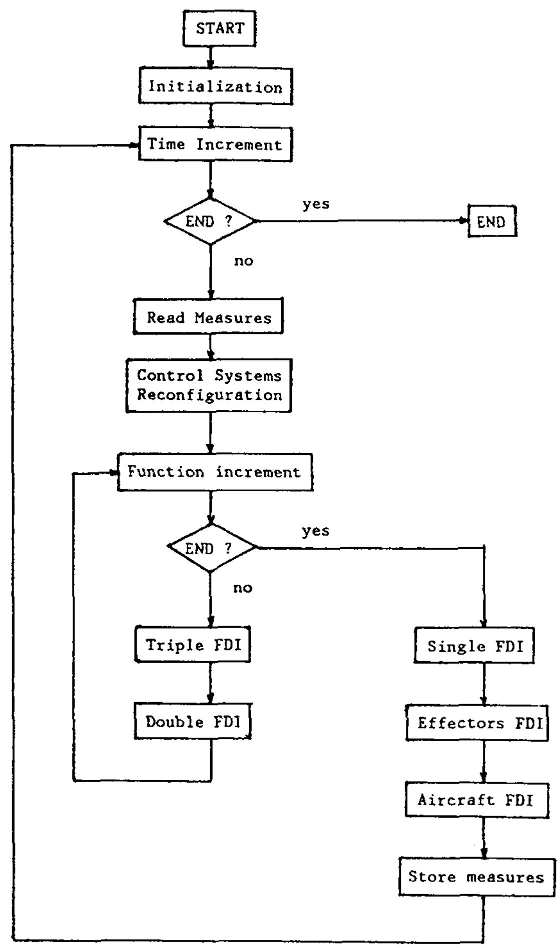
- PARALLEL AND ANALYTICAL REDUNDANCY
- DETECTION AND IDENTIFICATION OF FAILURES IN:
  - STATE SENSORS
  - CONTROL EFFECTORS
  - CONTROL-EFFECTOR SENSORS
  - AIRFRAME CHARACTERISTICS
- TRANSONIC BUSINESS JET EXAMPLE

OVERVIEW OF THE BASELINE CONFIGURATION



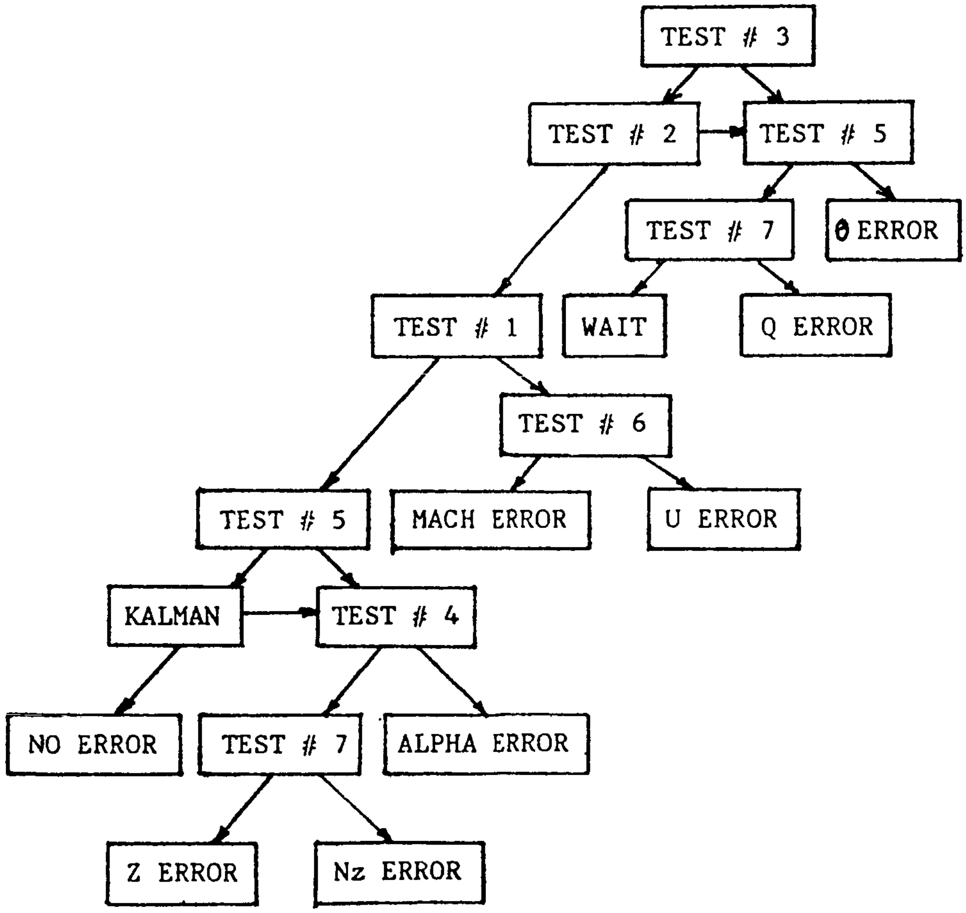
SIMULATION STRUCTURE

Simulation of the fault-tolerant control system was conducted using a general-purpose computer and the FORTRAN programming language. The simulation accounts for parallel redundancy in control system elements as well as analytical redundancy. The latter uses the mathematical relationships between dissimilar sensors to identify failures when it is suspected that one of two similar sensors has failed. It uses these same relationships to detect as well as identify failures when there is just one sensor of a kind. The logic distinguishes between failures of control effectors and failures of the sensors that measure control effector position. It also detects changes in aircraft dynamics, as might result from structural damage.



SINGLE-SENSOR FDI TREE

When there is no hardware redundancy remaining, failure detection and identification follows a tree structure, beginning with the simplest mathematical relationships between dissimilar sensors. For the most part, algebraic equations are used; however, it is necessary to use a Kalman filter to distinguish between angle-of-attack, manual-acceleration, and altitude sensor errors.



SINGLE-SENSOR STEP- AND RAMP-FAILURE

DETECTION TIMES

The threshold for failure detection was set just above the estimated 2.5-σ level. Step and ramp failures were simulated, with the results shown on the figure. The procedure generally was successful in detecting 5-σ step failures. It also could detect moderately steep (L/4) ramp-type failures; as the slope of the ramp decreased, detection times increased.

	Step 2.5 σ	Step 4. σ	Step 5. σ
M	No Detection	No Detection	Det. time = 6.60 sec.
q	No Detection	Det. time = 5.40 sec.	Not simulated
θ	No Detection	No Detection	Det. time = 21.60 sec.
α	No Detection	No Detection	Det. time = 31.80 sec.
Z	No Detection	No Detection	Det. time = 6.60 sec.
U	No Detection	No Detection	Det. time = 6.00 sec.
Nz	No Detection	No Detection	Det. time = 6.60 sec.

	Ramp L/4	Ramp L/7	Ramp L/10
M	Det. time = 15.00 sec.	Not Simulated	Det. time = 30.00 sec.
q	Det. time = 11.40 sec.	Not Simulated	Det. time = 24.60 sec.
θ	Det. time = 28.20 Sec.	Z Error detected	No detection in 60. sec.
α	Det. time - 28.20 sec.	Det. time = 34.20 sec.	Det. time = 60.0 sec.
Z	Det. time = 23.40 sec.	Det. time = 31.20 sec.	No detection in 60. sec.
U	Det. time = 15.00 sec.	Not Simulated	Det. time = 29.40 sec.
Nz	Det. time = 15.00 sec.	Not Simulated	Det. time = 29.40 sec.

EFFECTOR AND EFFECTOR-SENSOR

FAILURE DETECTION TIMES

Similar tests were made with errors in the control effectors and their sensors. These failures were detected quickly with 4-σ steps, and it was possible to distinguish readily between failures in the effectors and their associated sensors.

Additional results and conclusions are contained in the thesis by F. Dallery, "Failure Detection and Identification for a Reconfigurable Flight Control System," Princeton University Report No. MAE-1639T, Nov. 1983.

EFFECTOR FAILURES

	Step 2.5 σ	Step 4. σ	Ramp L/4.	Ramp L/10.
Elevator	No Detection	D.T = 4.80 sec.	D.T = 12.60 sec.	D.T = 24.00 sec.
Engine	No Detection	D.T = 5.40 sec.	D.T = 11.40 sec.	D.T = 24.00 sec.

FAILURES OF EFFECTOR SENSORS

	Step 2.5 σ	Step 4. σ	Ramp L/4.	Ramp L/10.
Elevator Sensor	No Detection	D.T = 4.80 sec.	D.t = 11.40 sec.	D.T = 24.00 sec.
Engine Sensor	No Detection	D.T = 4.80 sec.	D.T = 11.40 sec.	D.T = 24.00 sec.